

High Q^2 Physics at HERA and Searches for New Particles

T. Matsushita¹, E. Perez², R. Rückl³

¹ Department of Physics, University of Oxford, U.K., ZEUS Collaboration

² CEA-Saclay, DSM/DAPNIA/Spp, France, H1 Collaboration

³ Institut für Theoretische Physik, Universität Würzburg, Germany

Abstract. Preliminary results from H1 and ZEUS on Deep Inelastic Scattering (DIS) at high momentum transfer squared Q^2 are presented. Used are all available e^+p data accumulated by the H1 and ZEUS experiments between 1994 and 1997, corresponding to integrated luminosities of 37pb^{-1} and 47pb^{-1} , respectively. The anomalies observed at high Q^2 in the 1994 to 1996 data still remain, though with less significance. Since this high Q^2 domain represents a new frontier in DIS, the same data are used to search for new particles possessing direct couplings to lepton-quark pairs. Assuming that the slight excess of events observed in Neutral Current DIS is due to a statistical fluctuation, preliminary limits on the production of leptoquarks and of squarks in R-parity violating MSSM are presented.

1. Introduction

Deep Inelastic Scattering (DIS) of leptons by nucleons at the ep collider HERA offers an unique possibility to probe the proton at very small distances ($\simeq 10^{-16}\text{cm}$). The domain of very high momentum transfer squared Q^2 is also a window where first signs of physics beyond the Standard Model (SM) may manifest themselves.

Using 1994 to 1996 data, corresponding to a total integrated luminosity of about 35pb^{-1} , H1 [1] and ZEUS [2] experiments reported an observation of an excess of events in DIS at $Q^2 > 15000 \text{ GeV}^2$. This finding stimulated a lot of experimental and theoretical activity. Data accumulated during 1997 allowed to increase the statistics by roughly a factor 2.5. The measurements of DIS at high Q^2 based on all available e^+p data are presented and compared to the SM expectations in section 2. The same data are then used to search for new particles possessing direct couplings to lepton-quark pairs, namely leptoquarks and squarks in SUSY models where R-parity is violated (\mathcal{R}_p). Preliminary results on leptoquark production are shown in section 3, together with some remarks on particular phenomenological aspects at HERA. Analogous constraints on resonant \mathcal{R}_p -squarks production are presented in section 4.

2. Deep Inelastic Scattering at high Q^2 at HERA

2.1. Comparison of DIS data with the SM expectations

The full available e^+p data have been used by H1 and ZEUS experiments to update the measurements of Neutral Current (NC) and Charged Current (CC) DIS presented in [3, 4]. The distribution in Q^2 of the NC DIS events measured by H1 [3] is shown in Fig. 1a (all data, $\mathcal{L} = 37.4\text{pb}^{-1}$) and Fig. 1c (1997 data alone, $\mathcal{L} = 22.8\text{pb}^{-1}$), in comparison to the SM expectation. Also shown in Fig. 1b and Fig. 1d are the ratios of these measurements to theory. The curves above and below unity specify the $\pm 1\sigma$ levels determined from the combination of statistical and systematic errors of the NC DIS expectation. These errors are dominated by the uncertainty on the electromagnetic energy scale of the calorimeter and vary between 8.5% at low Q^2 and about 30% at the highest Q^2 . The NC DIS expectation agrees well with the data at $Q^2 < 10000 \text{ GeV}^2$, while at larger Q^2 deviations are observed with a slight deficit of events between 10000 GeV^2 and 15000 GeV^2 and a slight excess at $Q^2 \gtrsim 15000 \text{ GeV}^2$. The 1997 data alone suggest similar deviations, although with a more marginal significance. Table 1 summarizes the numbers of events observed by both experiments and expected in the SM with $Q^2 \ddagger$ above various thresholds Q_{min}^2 . At $Q^2 > 35000 \text{ GeV}^2$, ZEUS observes two events while 0.29 are expected. These events were reported previously [2]. In the 1997 data, no additional events were found in this Q^2 domain.

\ddagger Q_e^2 and $Q_{2\alpha}^2$ mean Q^2 reconstructed by the electron and double angle method, respectively.

Figure 1. (a) Q^2 distribution of the observed NC DIS events in comparison to the SM expectation (histogram); (b) ratio of the observed and expected number of events as a function of Q^2 ; (c,d) same as (a,b) but for the 1997 data alone.

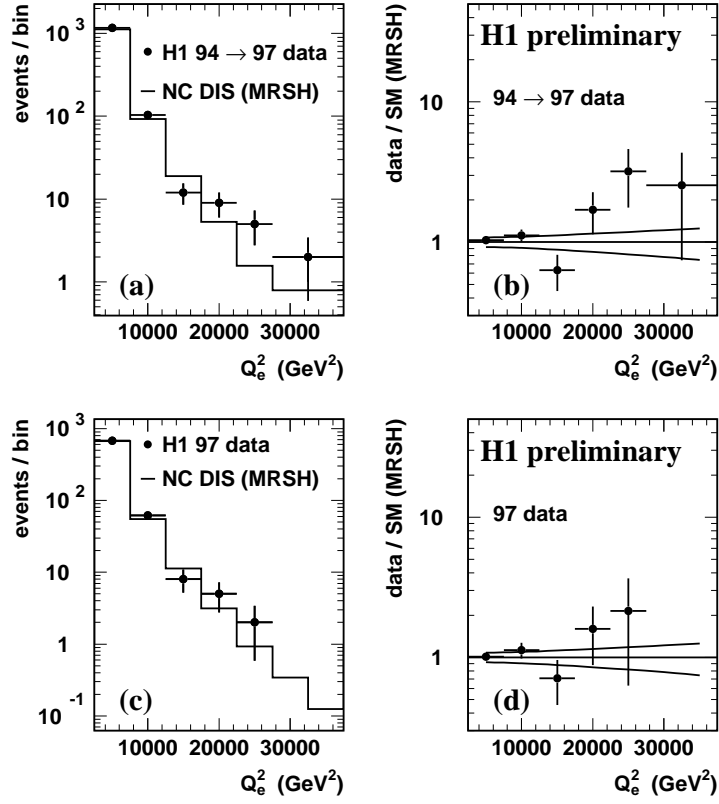


Table 1. Number of observed (N_{obs}) and expected (N_{exp}) NC DIS events with momentum transfer squared Q^2 above given thresholds Q_{min}^2 .

Q_{min}^2	Exp.	N_{obs}	N_{exp}
$Q_e^2 > 15000 \text{ GeV}^2$	H1	22	14.8 ± 2.1
$Q_{2\alpha}^2 > 15000 \text{ GeV}^2$	ZEUS	20	17 ± 2
$Q_e^2 > 25000 \text{ GeV}^2$	H1	6	1.6 ± 0.3
$Q_{2\alpha}^2 > 35000 \text{ GeV}^2$	ZEUS	2	0.29 ± 0.02

2.2. Differential Cross Sections

Differential cross sections in terms of Q^2 are derived by both experiments [3, 4, 5]. For that purpose, the number of events in each Q^2 bin is corrected for acceptance and migration, using Monte Carlo simulation, and for photon radiation and electroweak effects, using the HERACLES [6] program. Fig. 2 shows the NC and CC cross sections $d\sigma/dQ^2$ obtained by H1 and ZEUS.

For NC DIS, the rapid fall off of $d\sigma/dQ^2$ by about 6 orders of magnitude is on the whole well described by the SM prediction. However, as already mentioned, the

Figure 2. Differential cross sections $d\sigma/dQ^2$ for NC and CC DIS, measured by H1 (squares) and ZEUS (points), using all available e^+p data. The curves represent the SM predictions.

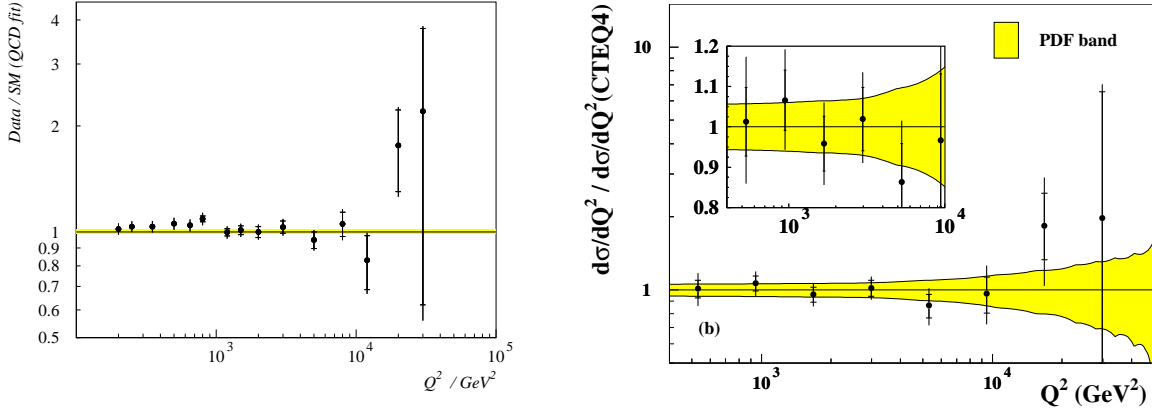
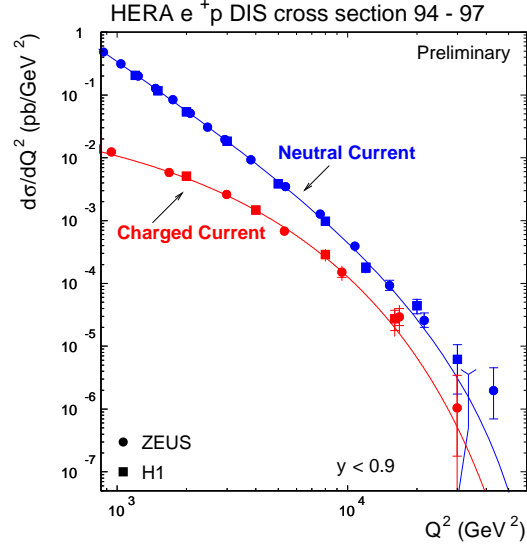


Figure 3. Left: ratio of the NC DIS cross section measured by H1 to the SM prediction. Right: ratio of the CC DIS cross section measured by ZEUS to the SM prediction. On both figures, the inner bars represent the statistical error and the outer ones the total error.

measurements slightly undershoot the SM expectation at $Q^2 \simeq 10000 \text{ GeV}^2$, while a slight excess of events is observed in the two highest Q^2 bins. The ratio of the experimental (H1) and theoretical NC cross section is shown in Fig. 3 (left). Here, the SM prediction is obtained from a NLO QCD fit performed by H1 [3], which includes the new H1 high Q^2 data as well as H1 and fixed target charged lepton-nucleon data at lower Q^2 . The inner error bars on the data points correspond to the statistical errors, while the outer ones indicate the full error, the typical total systematic error being about 4%.

For CC DIS, the Standard Model also provides a very good description of the data over most of the kinematic range as can be seen in Fig. 2. Only at the highest Q^2 the data show a tendency to lie above the SM prediction. The ratio of the measured (ZEUS)

to the theoretical (CTEQ4) $d\sigma/dQ^2$ distribution for CC DIS is shown in Fig. 3 (right). The shaded region indicates the theoretical uncertainty due to the uncertainties in the parton densities. As before, the outer error bars on the data points correspond to the total error. The main source of systematic error is the calorimeter energy scale. It leads to an error on the measured cross section of 5 – 10% in most of the Q^2 range, except at the highest Q^2 , where the error rises to about 50% [5].

The CC differential cross section $d\sigma/dx$ has also been measured by ZEUS and compared to the SM prediction. One can see some tendency in the data to lie above the expectation. If the CTEQ4 parametrization of parton densities is modified to give a larger d/u ratio at high x [7], the excess observed at high x relative to CTEQ4 becomes less significant [8].

3. Leptoquark Searches

3.1. Phenomenology

Leptoquarks (LQ) are scalar or vector bosons which carry both lepton and quark quantum numbers. They appear in many extensions of the SM. At HERA, LQs may be produced resonantly, via the fusion of the incident lepton with a quark or antiquark coming from the proton.

A reasonable phenomenological framework is provided by the BRW model [9]. This model is based on the most general Lagrangian that is invariant under $SU(3) \times SU(2) \times U(1)$, respects lepton and baryon number conservation, and incorporates dimensionless couplings of LQs to left- and/or right-handed fermions. Under these assumptions LQs can be classified into 10 isospin multiplets, half of which carry fermion number $F = 0$ and couple to $e^+ + q$, while the other half carries $F = 2$ and couples to $e^+ + \bar{q}$. The $F = 0$ ($F = 2$) class contains 2 (3) scalar and 3 (2) vector multiplets. In order to avoid stringent bounds from low energy experiments which would put LQs outside the reach of present day colliders, couplings are allowed to only one combination of fermion chiralities, and only within a single family. The couplings are generically called λ and are unknown parameters of the model. In the above model, first generation LQs only decay into $e + q$ and $\nu_e + q$ with fixed branching ratios, $\beta(eq) + \beta(\nu q) = 1$. We will use the nomenclature of [10] to label the different LQ states.

In the following analysis, it is assumed that only one of the LQ multiplets is produced at a time, and that the states within a given isospin multiplet are degenerate in mass. At HERA, LQs can be resonantly produced in the s -channel and exchanged in the u -channel. This is illustrated by the diagrams in Fig. 4. Obviously, the s - and u -channel processes do not interfere with each other, but each of these channels interferes with the SM γ and Z exchange. The relevant matrix elements can be found in [9]§.

§ The signs of the interference terms between standard model gauge boson contributions and fermion number $F = 0$ leptoquark contributions given in [9] are incorrect. The correct signs can be inferred from [11] and amount to multiplying the right-hand-side of Eqs (14d,e) and (17d,e) by (-1).

Figure 4. Illustrative diagrams for resonant LQ production in the s -channel (a) and u -channel LQ exchange (b).

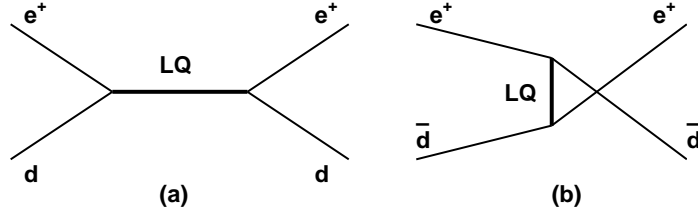
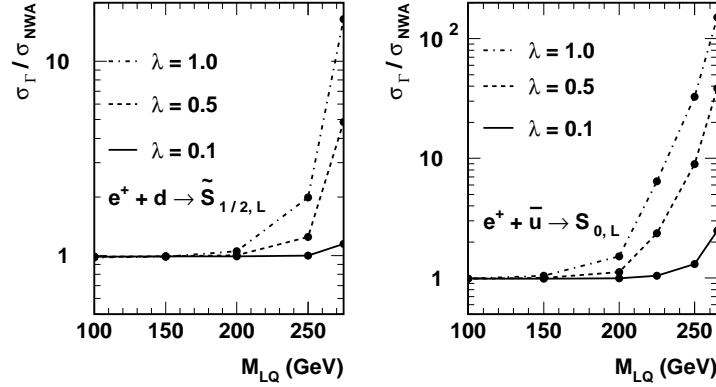


Figure 5. Ratio of the cross section σ_Γ for s -channel LQ production and finite LQ width Γ to the narrow-width approximation.

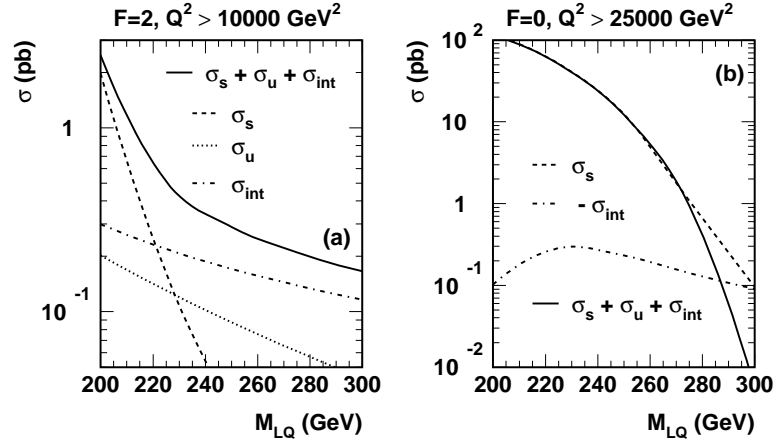


For the allowed strength of the couplings and in the mass range interesting for HERA, the decay width of a LQ into a lepton and a quark is generally small : $\Gamma_S = 3/2\Gamma_V = \lambda^2 M/16\pi \simeq 40$ MeV for $M = 200$ GeV and $\lambda = 0.1$, S and V referring to scalar and vector states, respectively. In the narrow-width approximation (NWA), the resonant production cross section is given by $\sigma_{NWA} = \frac{\pi}{4s}\lambda^2 q(x)$, $q(x)$ being the probability to find the relevant quark q in the proton with a fraction $x = M^2/s$ of the proton momentum. In the above, $\sqrt{s} \simeq 300$ GeV is the collision energy in the ep centre of mass and M is the LQ mass.

For high mass LQs, i.e. at high x , the parton densities in the proton are falling very steeply. At the same time, the LQ width increases with M leading to important tails at smaller values of x . As a result, the convolution of the parton density with the corresponding Breit-Wigner distribution gives a considerable larger cross section than the NWA. This is quantified in Fig. 5, for the typical range of couplings which can be probed at HERA with the current luminosity. One can see that for $F = 0$ and $\lambda = 0.5$ the deviation from NWA becomes noticeable at $M > 250$ GeV, while for $F = 2$ the finite width becomes non-negligible already at $M > 200$ GeV.

Furthermore, the u -channel contribution can also become large especially for $F = 2$ LQs and e^+p scattering where valence quarks are involved. A third effect which plays an important role at high M is the interference with SM γ and Z exchange. Depending on the LQ type, the interference can be constructive or destructive, and it can get comparable to or greater than the pure s - and u -channel contributions. In Fig. 6 the relative magnitudes of the various terms in the high Q^2 domain are shown for the $S_{0,R}$ ($F = 2$) and the $\tilde{S}_{1/2,L}$ ($F = 0$) scalar leptoquarks. For the $S_{0,R}$, the u -channel and the (positive) interference with SM DIS begin to dominate the s -channel cross section at $M > 220$ GeV. For the $\tilde{S}_{1/2,L}$, the u -channel contribution is negligible, but the

Figure 6. Contributions of the s - and u -channel processes and of their interference with SM DIS for (a) $S_{0,R}$ ($F = 2$) and (b) $S_{1/2,L}$ ($F = 0$). λ has been fixed to 0.5, a value which is typical for the experimental sensitivity in this mass range.



(negative) interference becomes important for $M > 285$ GeV.

3.2. Analysis

Resonant leptoquarks decaying into an electron and a quark jet lead to signatures which resemble NC DIS events. However, the signal could be identified as a resonance peak in the invariant mass distribution, with events in the peak showing an angular distribution specific to the spin of the leptoquark state. For example, the isotropic decay of a scalar LQ in its CM frame leads to a flat spectrum in y , where $y = (1 + \cos\theta^*)/2$, θ^* being the polar angle of the scattered lepton in this frame. This is remarkably different from the steeply falling $1/y^2$ distribution expected at fixed x for the dominant t -channel γ exchange in NC DIS events. Hence, a LQ signal should become more and more prominent at high y (or high $Q^2 = yM^2$). Consequently, it should be possible to optimize the signal to NC DIS background ratio by a mass dependent lower cut on y (or equivalently on $\cos\theta^*$). Note that this optimal cut depends not only on the spin of the LQ, but also on its fermion number, since the s - and u -channels, which lead to different angular distributions, contribute differently for $F = 0$ and $F = 2$.

The NC DIS candidates at $Q^2 > 2500$ GeV² observed by H1 are shown in Fig. 7a in the (M, y) -plane. Here, the full dataset was re-analysed including a new in-situ energy calibration for the electrons. This has led to slight migrations (within originally quoted systematic errors) of individual events in (M, y) . Fig. 7b shows the projected mass spectra, before and after applying the optimal y cut mentioned above. In the mass window considered in [1] of total width 25 GeV around 200 GeV, and at $y > 0.4$, 8 events are observed, while 3.0 ± 0.5 are expected from NC DIS. Out of these, 5 events originate from the 1994 – 1996 data and 3 from the 1997 data. Hence, the “mass clustering” around $\simeq 200$ GeV observed previously is not confirmed by the 1997 H1 data alone.

ZEUS searched for a resonance in positron-jet mass M_{ej} , without applying any constraints. The M_{ej} does not give the optimal resolution for LQ, however, it is free from initial state QCD and QED radiation shifts. The mean reconstructed mass is determined to be within 6% of the generated value, whereas the peak is on average 4%

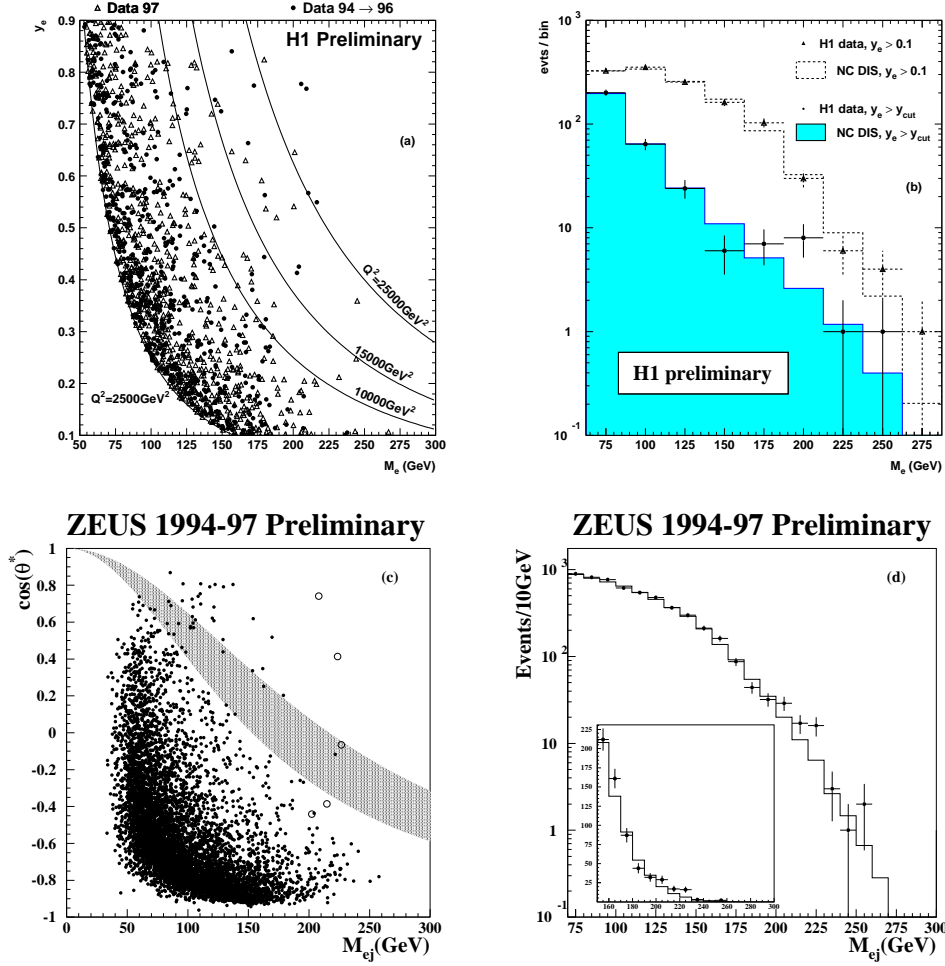


Figure 7. High Q^2 NC DIS candidates observed by the H1 (a,b) and ZEUS (c,d) experiments. (a) Events in the (M, y) -plane. Contours of fixed Q^2 are shown. (b) Mass spectra of the events before (triangles, dotted lines) and after (circles, solid lines) the optimal y cut. (c) Events in the $(\cos \theta^*, M_{ej})$ -plane. Shaded is the removed region which corresponds to the interface between calorimeters. Open circles show the high- x and high- y events reported previously. (d) Mass spectra of the events.

lower than the one obtained from a LQ MC. Fig. 7c shows the distribution of ZEUS NC DIS candidates in the $(M, \cos \theta^*)$ -plane. The fiducial cut applied on the positron which excludes the interface region between the central and forward calorimeters is indicated as the shadowed area. The projected spectrum of the invariant mass M_{ej} is shown in Fig. 7d. It is interesting to note that the outstanding high Q^2 events discussed in [2] tend to cluster around $M_{ej} \simeq 215$ GeV. At $M_{ej} > 200$ GeV and $\cos \theta^* > -0.2$, 4 events are observed which is in slight excess to the 1.2 events expected from NC DIS. On the other hand, for the events at $M_{ej} > 200$ GeV the angular distribution of the scattered positron is found to be similar to that expected from the SM [13].

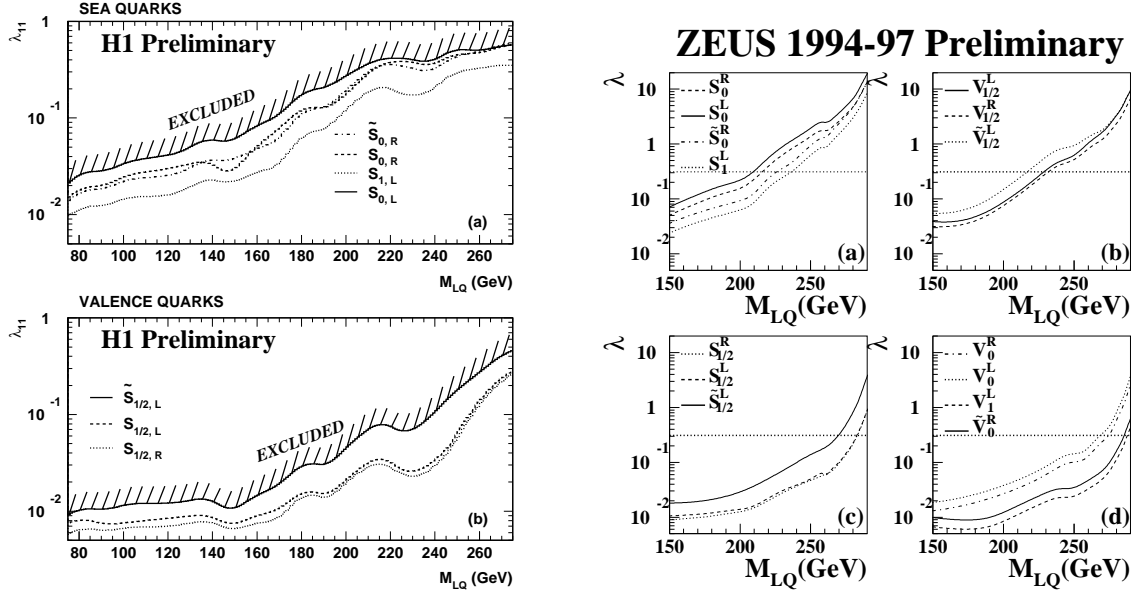


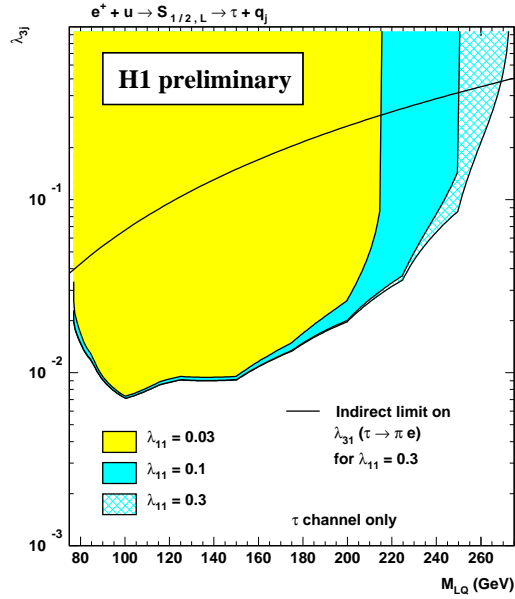
Figure 8. Left : H1 exclusion limits at 95% CL on the Yukawa coupling λ as a function of the LQ mass (a) for $F = 2$ and (b) for $F = 0$ scalar leptoquarks. Right : analogous limits from ZEUS (a) for scalars with $F = 2$, (b) vectors with $F = 2$, (c) scalars with $F = 0$, and (d) vectors with $F = 0$.

3.3. Results

Assuming that the slight excess of NC events observed at high Q^2 is due to a statistical fluctuation, H1 and ZEUS have derived preliminary limits on the Yukawa coupling λ as a function of the LQ mass, for all LQ species classified by BRW [9]. These are shown in Fig. 8. The discrepancy between the H1 and ZEUS bounds for high mass scalar LQs is due to the use of the NWA approximation by ZEUS in the calculation of the signal cross section, while H1 takes into account the LQ width by a Breit-Wigner distribution. For Yukawa couplings of electromagnetic strength, $\lambda^2/4\pi = \alpha_{EM}$, the existence of $F = 0$ LQs is excluded up to $M \simeq 275$ GeV.

Relaxing the BRW assumptions, the H1 Collaboration also obtained bounds in the plane β vs M , β being the branching ratio for $LQ \rightarrow eq$, for fixed values of the Yukawa coupling. The results can be found in [12] and in these proceedings [14]. For $\beta = 1$, TeVatron experiments exclude first generation LQ masses below $\simeq 242$ GeV [15], independently of any assumption on λ . Nevertheless, for low β , an important discovery potential remains for HERA. For example, if $\beta = 0.1$, the DØ experiment excludes masses only up to about 110 GeV, while H1 rules out masses below 255 GeV if $\lambda = 0.3$, and 210 GeV if $\lambda = 0.1$ [12]. The DELPHI [16] and OPAL [17] experiments at LEP recently performed a search for single LQ production and exclude LQ masses below 142 GeV for $\lambda = 0.3$, which because of the smaller centre of mass energy cannot be competitive with the sensitivity achieved at HERA.

Figure 9. Bounds on λ_{3j} , $j = 1, 2$, against the $S_{1/2,L}$ mass, for several fixed values of λ_{11} . The grey domains are excluded at 95% confidence level. The full curve indicates the most stringent indirect low energy limit on λ_{31} for $\lambda_{11} = 0.3$.



H1 also carried out a search for Lepton Flavor Violating LQs [12], looking for LQs decaying into $\mu + q_j$ and $\tau + q_j$ through the coupling λ_{2j} and λ_{3j} respectively. Mass dependent bounds on λ_{3j} are shown in Fig. 9 for several fixed values of λ_{11} . For $\lambda_{11} = \lambda_{3j} = 0.3$, H1 excludes LQs lighter than 255 GeV, which significantly improves the limit of about 100 GeV obtained from third generation LQ searches carried out at the TeVatron [19, 20], unless λ is much smaller. Indirect limits on λ_{31} are also improved by typically one order of magnitude.

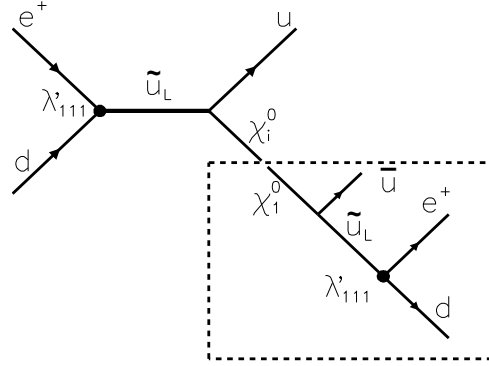
4. Searches for R-parity violating squarks

4.1. Phenomenology

The most general superpotential consistent with the gauge symmetry and supersymmetry of the Minimal Supersymmetric Standard Model (MSSM) contains Yukawa terms of superfields which violate lepton (L)– and baryon (B)–number. These interactions can give rise to rapid proton decay. In order to avoid this problem, one introduces additional discrete symmetries which forbid some or all of the dangerous Yukawa couplings. A radical solution is achieved by requiring R-parity conservation where R-parity is defined by $R_p = (-1)^{3B+L+2S}$, S being the spin of a given particle, so that the particle content of the MSSM can be classified in SM particles with $R_p = +1$ and superpartners with $R_p = -1$. The L – and B –violating Yukawa interactions in the superpotential being odd under R_p vanish. However, phenomenologically it is already sufficient to forbid the B –violating interactions and to constrain the L –violating terms such that they are

|| Note that the $ep \rightarrow \mu + \text{jet} + X$ events observed by H1 and discussed in [18] fail significantly the kinematical constraints that should hold for the process $eq \rightarrow LQ \rightarrow \mu q$.

Figure 10. Illustrative example of resonant squark production followed by R_p -violating and conserving decays into e^+ and jets.



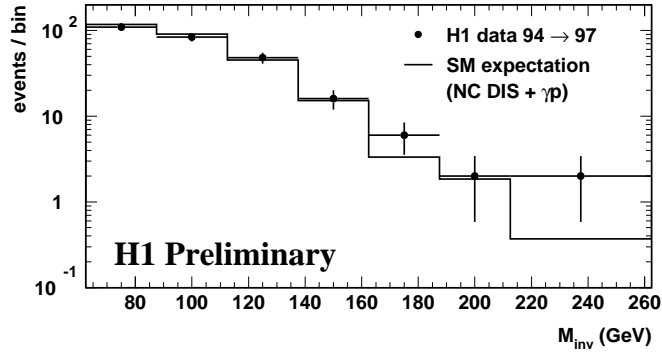
consistent with the remaining, much weaker experimental bounds.

In such a scenario one can have the term $\lambda'_{ijk} L_i Q_j \bar{D}_k$ in the superpotential, where L_i and Q_j are the lepton and quark $SU(2)_L$ -doublet superfields, respectively, \bar{D}_k is the down-quark $SU(2)_L$ -singlet superfield, and λ'_{ijk} denote the dimensionless Yukawa couplings. The indices i, j, k refer to the fermion generations. Most interestingly at HERA, the R_p -violating couplings with $i = 1$ can give rise to resonant squark production [22] ¶. In e^+p scattering, the possible production channels are $e^+ \bar{u}_j \rightarrow \tilde{d}_{Rk}$ and $e^+ d_k \rightarrow \tilde{u}_{Lj}$. In particular valence d quarks allow to probe \tilde{u}_{Lj} squarks and λ'_{1j1} couplings. The present indirect bounds on λ'_{1j1} and $M_{\tilde{q}}$ [26] leave an interesting search window for HERA with the exception of λ'_{111} in which case the limit from neutrinoless $\beta\beta$ decay precludes the observation of effects at HERA. The possible squark interpretations of the observed excess of events in NC DIS reported in [1, 2] have been studied in detail in [27, 28, 29, 11].

In the following, we consider scenarios with a single nonvanishing coupling λ'_{1j1} . Furthermore, we assume that gluinos are heavier than squarks, so that $\tilde{q} \rightarrow \tilde{g} + q$ is kinematically forbidden. The resonantly produced squark can then decay into $e + q$ via the R_p -coupling λ'_{1j1} resembling a scalar leptoquark, and into a neutralino χ_i^0 or a chargino χ_i^\pm plus a quark via R_p -conserving gauge interactions. In the latter cases, the final state is determined by the subsequent neutralino and chargino decays. The heavier gauginos may cascade down to the lightest one, while the lightest neutralino may finally decay into $e^\pm q \bar{q}'$ or $\nu q \bar{q}$, involving again the coupling λ'_{1j1} . Similar R_p -decay channels exist for the χ^+ with the exception of the e^- -mode. An illustrative example is shown in Fig. 10. In [23], a classification is given of all possible final states in terms of several distinguishable event topologies. Recently, the SUSYGEN [30] package has been extended to include R_p -SUSY processes at HERA. The new version which will be released shortly allows a complete event generation for all possible channels.

¶ Further studies of R_p -processes at HERA can be found in [23, 24, 25].

Figure 11. Invariant mass spectrum of $e^\pm + \text{multijet}$ final states for data (symbols) and NC DIS expectation (histogram).



4.2. Analysis

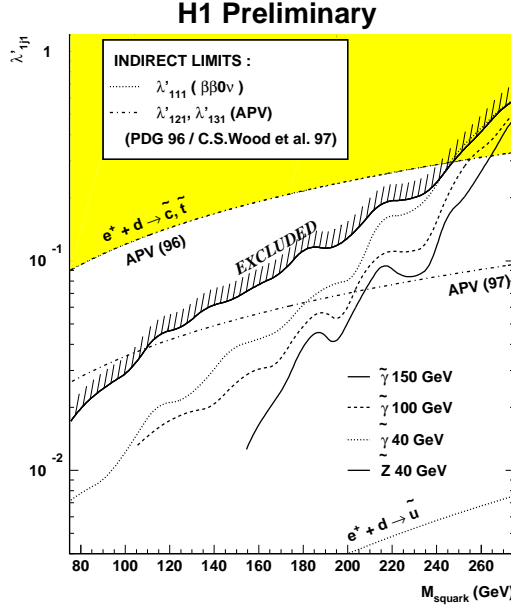
The H1 Collaboration [21] analysed final states containing an e^\pm and several jets. Since the lepton appears late in the cascade decay chain, it is expected to be degraded in energy. Consequently, the main selection criteria require an e^\pm candidate reconstructed at high y_e together with two forward jets. The invariant mass spectrum of the 289 events selected is shown in Fig. 11 and compared with the distribution of the 285.7 ± 28.0 events expected in the SM. The agreement is good. In the “wrong sign” channel, $e^+ + p \rightarrow e^- + \text{multijet}$, one candidate is observed, while 0.49 ± 0.2 are expected.

4.3. Results

Combining the LQ-like channel $e^+ + \text{jet}$ with the $e^\pm + \text{multijet}$ channels, one can put mass-dependent limits on the couplings λ'_{lj1} . To this end, four different sets of values have been chosen for the MSSM parameters μ , M_2 and $\tan \beta$, leading to four typical scenarios for the lightest neutralino : photino-like states with mass 40, 100, and 150 GeV, and a zino-like state with mass 40 GeV. Given λ'_{lj1} and the squark mass, the relevant widths and branching ratios are fixed. The H1 analysis shown in Fig. 12 excludes squark masses up to 262 GeV for $\lambda'_{lj1} \simeq 0.3$. As expected, in the case of λ'_{111} , the H1 bound is not competitive with the best indirect constraint coming from the non-observation of neutrinoless $\beta\beta$ decay. However, for λ'_{121} and λ'_{131} , the best indirect limits from atomic parity violation are improved by the H1 direct bounds in a large region of the parameter space. Especially, for large χ_1^0 masses, the upper bounds on λ'_{121} and λ'_{131} are decreased by as much as a factor 4.

The \mathcal{R}_p squark scenarios considered above are also constrained by the first generation LQ searches at the TeVatron. However, these bounds become rather weak when $\beta(\tilde{q} \rightarrow e + q)$ is small, a possibility which exists due to the presence of R_p -conserving decays. Recently, the TeVatron experiments have performed a dedicated \mathcal{R}_p search [31, 32] analysing final states with like-sign electrons plus jets. These may originate from the decay of pair-produced squarks. Assuming five degenerate squark flavours, squark masses below 252 GeV are excluded. If one squark (e.g. the lightest stop) is much lighter than the others, the cross section is significantly smaller. The

Figure 12. 95% CL upper limits on the coupling λ'_{1j1} as a function of the squark mass, for different masses and composition of the lightest neutralino χ_1^0 . The most stringent indirect limits from neutrinoless $\beta\beta$ decay and atomic parity violation are also indicated.



corresponding mass bound is estimated [21] to decrease to about 150 GeV.

5. Conclusions

Results on neutral and charged current Deep Inelastic Scattering at high momentum transfer derived from the e^+p data taken by the H1 and ZEUS experiments in 1994–1997, have been presented and compared to the Standard Model expectations. The differential cross sections in terms of Q^2 are found to be in good agreement with the SM predictions. A slight excess at high Q^2 observed in the 1994–1996 data still persists with the 1997 data included, but with less significance.

Using the same data, a search for leptoquarks and for squarks with R-parity violating couplings has been performed. No evidence was found for the existence of such species. The resulting bounds on leptoquark/squark masses and Yukawa couplings to lepton-quark pairs improve the constraints from other colliders and from low energy experiments in important regions of the parameter space.

Acknowledgments

TM would like to thank the British Council, Collaborative Research Project TOK/880/11/15. RR acknowledges support by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Bonn, Germany, Contract 05 7WZ91P (0).

6. References

- [1] H1 Collaboration, C. Adloff *et al.*, Z. Phys. C74 (1997) 191.
- [2] ZEUS Collaboration, J. Breitweg *et al.*, Z. Phys. C74 (1997) 207.

- [3] H1 Collaboration, “Measurement of Neutral and Charged Current Cross-Sections at high Q^2 ” Contributed paper # 533 to the XXIX Int. Conf. on High Energy Physics (ICHEP98), Vancouver, Canada (23-29 July 1998).
- [4] http://www.desy.de/~quadt/talks/desy_130398/desy_seminar.html;
ZEUS Collaboration, “Measurement of High- Q^2 Neutral-Current DIS Cross Sections at HERA” Contributed paper # 752 to ICHEP98.
- [5] ZEUS Collaboration, “Measurement of High- Q^2 Charged-Current DIS Cross Sections at HERA” Contributed paper # 751 to ICHEP98.
- [6] A. Kwiatkowski, H. Spiesberger and H.-J. Möhring, Comput. Phys. Commun. 69 (1992) 155.
- [7] W. Melnitchouk and A.W. Thomas, Phys. Lett. B377 (1996) 11;
W. Melnitchouk and J.C. Peng, Phys. Lett. B400 (1997) 220;
A. Bodek, U.K. Yang, “Parton distributions at high x”, to be published in proceedings of the 6th International Workshop on Deep Inelastic Scattering and QCD, Brussels, Apr. 1998.
- [8] A. Bodek, E. Rizvi, WG1 contribution, these proceedings.
- [9] W. Buchmüller, R. Rückl and D. Wyler, Phys. Lett. B191 (1987) 442.
- [10] B. Schrempp, Proc. of the Workshop Physics at HERA, DESY, Hamburg (1991), vol. 2 p. 1034, and references therein.
- [11] J. Kalinowski, R. Rückl, H. Spiesberger and P.M. Zerwas, Z. Phys. C74 (1997) 595.
- [12] H1 Collaboration, “A Search for Leptoquark Bosons in DIS at High Q^2 at HERA” Contributed paper # 579 to ICHEP98.
- [13] ZEUS Collaboration, “Search for Narrow High Mass States in Positron-Proton Scattering at HERA” Contributed paper # 754 to ICHEP98.
- [14] D. Waters, plenary talk, these proceedings.
- [15] Leptoquark Limit Collaboration Working Group (for the CDF and $D\bar{0}$ collaborations), hep-ex/9810015, 6 Oct. 1998.
- [16] DELPHI Collaboration, “Searches for Single Leptoquark Production at $\sqrt{s} = 161$ GeV and $\sqrt{s} = 172$ GeV with the DELPHI Detector”, Contributed paper # 352 to the International Europhysics Conference on High Energy Physics, Jerusalem (EPS97), Israël (19-26 August 1997).
- [17] OPAL Collaboration, “Search for Single Leptoquark Production in Electron-Photon Scattering at $\sqrt{s} = 161$ and 172 GeV, Contributed paper # 205 to EPS97.
- [18] H1 Collaboration, C. Adloff *et al.*, DESY preprint 98-063 (May (May 1998), hep-ex/9806009. See also these proceedings.
- [19] $D\bar{0}$ Collaboration, B. Abbott *et al.*, FERMILAB preprint PUB-98-081-E (March 1998) 6pp.; eprint hep-ex/9803009.
- [20] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. 78 (1997) 2906.
- [21] H1 Collaboration, “A Search for Squarks of R-Parity Violating SUSY at HERA”, Contributed paper # 580 to ICHEP98.
- [22] J. Butterworth and H. Dreiner, Nucl. Phys. B397 (1993) 3, and references therein.
- [23] H1 Collaboration, S. Aid *et al.*, Z. Phys. C71 (1996) 211.
- [24] E. Perez, “Recherche de Particules en Supersymétrie Violant la R-parité dans H1 à HERA”, Ph.D. thesis, Université Paris VI, DAPNIA/SPP report 96-1008 (in French).
- [25] H. Dreiner, E. Perez, Y. Sirois Proceedings Workshop “Future Physics at HERA”.
- [26] H. Dreiner, hep-ph/9707435, To be published in ‘Perspectives on Supersymmetry’, Ed. by G.L. Kane, World Scientific.
- [27] G. Altarelli *et al.*, Nucl. Phys. B506 (1997) 3.
- [28] D. Choudhury and S. Raychaudhuri, Phys. Lett. B401 (1997) 54.
- [29] H. Dreiner and P. Morawitz, Nucl. Phys. B503 (1997) 55.
- [30] S. Katsanevas, P. Morawitz, “SUSYGEN 2.2: A Monte Carlo Event Generator for MSSM sparticle production at e^+e^- colliders”, hep-ph/9711417, 68pp. The SUSYGEN package has been extended by E. Perez to R_p SUSY processes at HERA.
- [31] $D\bar{0}$ Collaboration, “Search for R-parity Violating Supersymmetry in the Dielectron

and Multijet Channel” Contributed paper #588 to ICHEP98; see also <http://www-d0.fnal.gov/public/new/analyses/rpareejjjj/welcome.html>.

- [32] M. Chertok, for $D\bar{0}$ and CDF Collaborations, to be published in the Proceed. of the 33rd Rencontres de Moriond, QCD and High Energy Hadronic Interactions, Les Arcs, France, (March 21-28, 1998).